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PRODUCTIVITY PANICS – POLEMICS AND REALITIES

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Abstract

Widespread uneasiness has emerged concerning a perceived slowdown in productivity growth. The question posed here is whether our destiny is indeed tied to inexorable movements in productivity and innovation, whatever these things may be, or can we build a future contingent upon collective choices and guided by human needs and desires?

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Introduction

Movements in an economy's productivity have moved centre stage in public discussion. With only slight exaggeration, a broad mainstream consensus on the issues under consideration can be outlined as follows:

1. *Growth in productivity is 'everything'.*

This consensus, as exemplified by Wolf (2018), asserts that we are in the midst of a crisis: 'We live in an age judged to be one of exciting technological change, but our national accounts tell us that productivity is almost stagnant. Is the slowdown or the innovation an illusion? If not, what might explain the puzzle? The slowdown, if true, matters. As Paul Krugman… argued, "Productivity isn't everything, but in the long run it is almost everything." Improvements in standards of living depend almost entirely on rising output per worker'. The productivity slowdown, Wolf says, is a major explanation for the stagnation in real incomes and the pressure for fiscal austerity in high-income countries. A graph is presented showing a decline in growth (% pa) in US total factor productivity (TFP) since the 1970s. Wolf then offers, as a possible explanation, another graph suggesting weak investment and declining growth of productivity in, specifically, high tech sectors. 'Without innovation, the rising prosperity of the past two centuries would have been impossible. In truth, innovation, not productivity, is almost everything'.

Wolf's article, typical of its kind, with its gloomy picture of economic stagnation due to lack of innovation, sits somewhat uneasily alongside notions of catastrophic job displacement due to the incursions of Artificial Intelligence (AI) and robotics (see, for instance, Ford,2015), an equally fatalistic vision of the trajectory of economic and social life.

Two further propositions are part of this mainstream consensus:

2. *The source of productivity growth is technological innovation (most likely emerging from profit-making enterprises);*

3. *Leading nations need to focus upon, and direct their efforts to, the development of high technology sectors.*

The response to these three propositions will unfold below as follows:

1. Productivity, GDP and other economic aggregates are constructed using price weights in their calculation, and are thus inextricably tied to a social valuation. The focus on productivity is an attempt to find a purely technical, or even objective, measure of (actual or potential) material improvement that would obviate the need for the making of social choices and confronting conflicts between interests and groups in society. This search for a purely technocratic solution (hinting at Pareto-type improvements) to issues of economic development is a vain pursuit.

2. The widespread influence in contemporary discourse on the role of innovation and creative destruction can have a deleterious influence on approaches to economic development. It represents a misreading of history and leads to a misguided search for technological fixes and forms of techno-nationalism.

3. It is false to suggest that we are locked into a 'there is no alternative' trajectory due to the technologically-driven imperatives of economic and productivity growth. We have a range of options open to us and, indeed, will find this process of choice-making unavoidable.

The central question here is whether our destiny is indeed tied to inexorable movements in productivity and innovation, whatever these things may be, or can we build a future contingent upon collective choices and guided by human needs and desires?

Productivity and social valuation

The argument presented by Wolf and others thus asserts that increases in productivity – in output[1] for given levels of input, including human labour – are 'almost everything' when we wish to explain long term trends in economic growth in the modern period. This proposition plays a central, if often implicit role in the 'rise of west' literature (Jones, 1981) concerning the ascent to supreme power in the past half millennium of western Europe, with its focus on scientific and technological achievements (alongside juridical and governmental aspects – property rights – said to be unique to the west), as opposed to success in enslaving and exploiting non-Europeans and the taking possession of lands and resources occupied by them.[2] The focus on enhanced productivity, beyond any such role in historical analysis or in exculpatory polemics, is linked to the search by economic analysts, from as far back as Adam Smith or earlier, for a deep-seated explanation for the wealth of nations in terms of such real factors as efficacy in the use of labour (e.g. Smith's division of labour), rather than accounting for a nation's success by superficial and transitory aspects such as the accumulation of gold and silver or, in our day, alterations in governmental monetary and fiscal policy. However, even if, for the sake of argument, were we to accept this notion of productivity growth as the ultimate cause of overall material improvement, it would not in any straightforward way suggest, as we shall see, an economic strategy of giving exclusive attention to investment and growth of productivity in sectors deemed high tech, or even those perceived to yield high productivity growth rates: for a national economy, such an approach would make about as much sense as a chess strategy having a primary and immediate focus on attacking the king. The latter strategy, as I have found to my chagrin, rarely leads to the desired goal.

Charting the trajectory of national productivity can be a tricky business. The higher the levels of aggregation we are working at, the more we have to rely on financial calculation weighted by prices rather than a hand's-on physical enumeration - we are a long way from simply counting how many more widgets are produced with a given amount of labour when new widget-making machines are introduced:[3] the monthly statistics on movements in coal production (in, if I remember, metric tonnes) in my monthly copies of the Soviet journal *Ekonomicheskaya Gazeta* seemed to be yielding more useful information (despite quality issues even in the case of coal) than the equivalent calculations of growth in the machine tool sector, the latter cobbled together in roubles using heaven knows what price weights.

The national trends in productivity cited above use a measure of TFP, as opposed to some calculation of output per unit labour input, to compensate for the fact that, for instance, Danish agriculture is bound to look 'unproductive' compared with Canadian extensive techniques on an output per head calculation, even if its overall efficiency is comparable. Total factor productivity growth emerges from statistical regression technique and 'is the component of overall output growth that cannot be explained by accounting for changes in observable labor and capital inputs'. It is therefore, as Moses Abramovitz has suggested, a measure of our ignorance. (Brynjolfsson et al., 2017)

This ignorance manifests itself in various ways in dealing with labour and capital, issues which are well covered in the existing literature.[4,5] Of particular interest here are the issues linked to the complementarity of inputs, which introduce additional difficulties. Thus, statistical calculations of TFP growth conclude by showing that it accounts for a certain fraction of growth (as do labour and capital). Such a conclusion, however, 'would be misguided', because 'it ignores the fact that decisions to invest in physical and human capital are themselves likely to depend on TFP growth', (World Bank, 2000) so that the *ex post* calculations may not be a good guide to the *ex ante* dynamics of growth.[6] For developing countries, the process of diffusion and the assimilation of technologies from other nations is the major task before them, rather than innovation: the success of South Korea, Taiwan and mainland China in adapting world technologies has been linked to their prior achievements in education and economic equality (the latter in all cases abandoned at later stages) at the time of their respective economic take-offs. Even in an advanced sector such agriculture in the present-day US, complementary infrastructural aspects have played a central role, with technical change coming primarily from increased innovation through public research and improvements in human capital, the latter linked not only to education, but to access to health care. (Sabasi and Shumway, 2015) In this case and others, an exclusive focus on the technological aspects of innovation and diffusion is likely to be dysfunctional.

The presence of these complementary aspects in the process of economic development points to the limits, as we shall see below, of using new technology as a method for by-passing the necessity for human and physical infrastructural development and 'leaping over' to a condition of higher productivity. In addition, the presumption embodied in statistical tests that the inputs involved are being used in an optimal fashion will distort the values attributed to the individual components (Salter, 1969, pp.6-7) and reinforces a mentality of relying on a technological fix rather than attempting to correct failures in the context of present-day technology.

In fact, TFP and output per unit labour cost usually move in tandem,[7] with only specific demographic movements (e.g. an increase in female participation in the US) causing any substantial deviation between the two: the worrisome possibility persists that global movements in productivity growth, far from explaining movements in per capita GDP, are largely registering a quasi-tautological connection.[8,9] Such globally-based productivity measures, as opposed to those attempting to trace changes in a particular industry or sector, also run into the possibility that the causative relation between growth in productivity and in per capita GDP moves in the opposite direction. The dominant explanations from Wolf and others are 'supply side', i.e. slower growth in productivity will result in stagnating GDP per capita, but 'demand side' explanations exist as well,[10] some of them associated with mainstream Keynesianism, (Summers, 2014) but rarely crediting an older, heterodox literature from Nicholas Kaldor concerned with what he dubbed 'Verdoorn's law' suggesting that an economy whose GDP is rising rapidly will be observed to have accelerating growth in productivity for two reasons: first, in the act of pursuing higher levels of production during a phase of rapid growth, an economy or sectors within it will develop more efficient techniques in the process, a 'learning by doing' effect (anticipating endogenous growth notions), and second, such an economy will manifest increases in productivity through the realisation of economies of scale and (in the short run) by making fuller use of its otherwise redundant capacity. (McCombie and Spreafico, 2016)

At least some of the difficulties in measuring globally-based productivity and its direction of causation emerge from ambiguities in the interpretation of the GDP measure itself – the variable whose growth plays the role of maximand in the standard exposition of a relationship between changes in productivity and in GDP. And a reconsideration of GDP will inevitably raise questions concerning why precisely we are concerned with declining national productivity in the first place. The GDP measure serves multiple functions: it is a measure of total economic capacity (hence the journalistic excitement when the GDP of China has supposedly surpassed that of the US); a direct measure (in per capita terms) of a nation's welfare or standard of living; it is, lastly, a measure of aggregate demand for the purposes of macroeconomic regulation of the economy. Each of these notions gives us a different angle on why we might view falling productivity growth to be linked to a crisis.

First, interpreting falling GDP growth as a slowdown in the expansion of economic capacity might indicate that resources (including human labour) are being released at a slower rate than heretofore from some sectors that, if successfully reallocated (with the maintenance of full employment conditions), would have been available for a range of purposes: to generate increases in the consumption of goods and services by the general public, to fulfil national political goals such as military expansion, or for 'good things' such as poverty alleviation. For this latter task especially, the constraint of resources consequent on this slowdown is often taken to be a binding one since, as we have seen above, statistical procedures presume that existing resources (e.g. labour and capital) are already being used efficiently, and in the contemporary political context any significant reallocation of resources presently dedicated to serving the needs and desires of the well-off – a proportion that has swelled substantially in the past four decades in, especially the US and the UK – is considered unthinkable. Thus, 'it is productivity growth which enables economic growth…if we have to devote ever more resources to finding and developing those new technologies then we'll end up running out of resources to do so and thus economic growth will fail to happen.' (Worstall, 2016)

In its second use, as a direct measure (in per capita terms) of a nation's welfare or standard of living, declining productivity growth can be interpreted as resulting in a situation in which the capitalist economy is only providing us with new commodities to delight us at a declining rate. Robert J. Gordon is perhaps the leading figure suggesting that the large gains in labour productivity from the late nineteenth century until the early 1970s in the US will not be repeated. (Gordon, 2016) His claims have had a wide reception, since he had been practically a lone voice suggesting that the productivity surge of the mid 1990s observed in US statistics was less likely a reflection of the widely heralded new economy based on computer technology than a transitory phase reflecting largely economy-wide cyclical factors and rapid increases in the productivity of the computer industry itself. (Gordon, 2000) According to him, the low hanging fruit have been picked: the electronics revolution, a general purpose technology (GPT), has not yielded, and will not yield the gains to productivity and to consumer welfare comparable to the Second Industrial Revolution: 'The inventions of the second industrial revolution between 1870 and 1920 and then between 1920 and 1970 created the most rapid period of growth in labor productivity experiences in American history, bringing an utter change in most dimensions of human life. The inventions of the third industrial revolution…entertainment, communication and information technology – did not have the same effects on living standards as had electricity, the internal combustion engine, running water, improved life expectancy…and the human condition as work hours declined from 60 to 49 hours a week'. Furthermore, 'we don't eat computers or wear them or drive to work in them or let them cut our hair. We live in dwelling units that have appliances much like those if the 1950s and we drive in motor vehicles that perform the same functions as in the 1950s, albeit with more convenience and safety'. (Gordon, 2016, pp.522, 579) We see here an odd conflation: the discussion is dominated by references to productivity growth decline, but the real problem being underlined is that of old-fashioned diminishing marginal utility – that innovations in earlier periods were just more important to human welfare than twenty-first century tweaks on electronic devices (an evaluation that suggests that earlier developments offered more than merely higher levels of growth of subjective utility, but were more successful at fulfilling fundamental human needs). It would be a mere coincidence if improvements in social welfare from technological improvements moved in step with gains in productivity, and Gordon (2016, pp.566-7) tries to square the circle by writing that 'innovation since the 1970s…has been less broad in its scope than before'. But in fact, 'technologies might deliver substantial utility even if they account for a small share of GDP due to their low relative price', (Brynjolfsson et al., 2017) a stunning example being the discovery that a simple solution of salt, sugar and water could serve for the control of diarrhoeal dehydration in children (in, especially, poor countries) that has been hailed as one of the great medical breakthroughs of modern times. (Ruxin, 1994)

Perhaps if we are disappointed in the improvements in human welfare that have taken place since 1970 we should look elsewhere than declining productivity. In general, 'productivity' appears before us as something which, in principle, can be measured in an objective manner. But the social valuation of any productivity-enhancing activity, very much like a capital good, is ultimately linked to that of the final output, i.e. consumption, which it helps facilitate. The 'tremendous consumer benefits' (Byrne et al., 2016) from smartphones, Google searches, and Facebook has been carefully calculated 'using data on time use and the opportunity cost of people's time (i.e., the wage)'. (Goolsbee and Klenow, 2016) In the end, however, any such exercises in applied Benthamism for evaluating these productivity gains are no less subjective (i.e. they embody value judgements) than any other, including my own that, seen from the perspective of the forms of world-wide deprivation referenced above in the context of childhood dehydration, the application of this general purpose technology (GPT) to enhancements of the 'consumer experience' should not be valued very highly, despite the enormous commitment of talent, energy and resources devoted to their development. Whether one agrees or not with this judgement, it highlights the fact that the calculation of the social benefits to the introduction of even a multi-purpose GPT such as semiconductor-based electronics cannot take place on the basis of an uncontentious, objective measurement of how much society's technological frontier has been extended, but only in the context of a crystallisation of societal decisions on the substantive uses made of this technology: we then have to attach a value to these uses.

GDP as a welfare measure raises further issues when considering productivity growth. Let us suppose that a national productivity slowdown had indeed been observed in aggregate statistics, but has not been successfully located in any particular sector. What if, in fact, we were not at all observing a declining productivity growth in individual sectors of the economy but an exogenous shift in 'taste' to a low productivity sector, as a newly-endowed super rich class indulges in its preference for maids and butlers in the home? Such a shift in taste might more represent the harvesting of the fruit of past increases in productivity rather than a productivity slowdown per se: since it emerges from the free choice of consumers, it would be difficult, in orthodox economics, to identify such a deceleration in measured productivity growth with any decline in the rate of improvement in general welfare.[11] And if the shift taking place were in the direction of the labour intensive, low productivity education sector whose output is registered at cost in the national accounts, could we simply be miscalculating the long term effects on productivity? 'If our contemporary obsessions with "the" growth rate had then been in place [in Japan after 1868], would not an imaginary pre-First World War IMF have called for less investment in school facilities in Japan and more in silk production?' (Auerbach, 2016, p. 290) It will be suggested below that such misunderstanding about the long term productive effects of increased expenditure on education might apply as well to such items of 'consumption' as improved housing facilities for households on lower income.

GDP has a third use as a tool in macroeconomic regulation - as a measure of aggregate demand. From this perspective, a productivity slowdown can generate a crisis by reducing incentives for investment from the private sector, which then acts to frustrate goals such as the maintenance of full employment. Wolf's story concerning the crisis emerging from declining productivity growth, like that of others, is largely an amalgam of the (quite different) economic capacity and aggregate demand perspectives, but most analysts are united in declaring that this decline is a (very) bad thing, except for those, from a seemingly opposite perspective, are bewailing the fact that we are all about to be displaced by robots. The aggregate demand story may, in fact, play a bigger role than first appears in explaining this negative attitude: if one were merely concerned with declining productivity because of its effects on slowing GDP growth from a welfare and/or capacity perspective, one could, in fact, treat such a development in a positive manner: 'declare victory' and suggest that the economy, having successfully exhausted the stock of important and useful inventions, can now focus on social improvement through redistribution of resources in the context of a nineteenth century vision of a steady-state economy. But the near unanimity with which this declining productivity story is greeted by economists as a catastrophic event suggests the fear that this decline will result in the drying up of 'animal spirits' in the business community, leading to reduced investment and secular stagnation: 'Capital deepening is indirectly influenced by technological change because firms' investment decisions respond to improvements in capital's current or expected marginal product'. (Brynjolfsson et al., 2017) The possibility of a soft landing or steady state has never been on the cards for most economists.[12]

Attempts at analysing national trends in productivity also take place through the examination of individual sectors. The ideal would be to get as close as possible to a hand's-on physical calculation - counting how many more widgets are produced with a given amount of labour when new widget-making machines are introduced, taking into consideration, as noted above, the possibility of qualitative differences from the existing output, and the need to set a value on the output of new commodities in the context of technological change (this problem was an acute one in the context of the Soviet machine tool sector mentioned above). The introduction of the new machines is unlikely to be a *ceteris paribus* event – it may well be accompanied by changes in work routines and practices in the sector under consideration that, in principle, are not to be viewed as rises in productivity per se, such as work intensification. And once we choose to examine changes in productivity one sector at a time, we must be wary of complications due to Marshallian-type externalities, so that, for instance, an exclusive focus on increases in productivity in the agricultural sector may distract us from tracing this rise to its true provenance - improvements in the electronics of machine tools used in the making of tractors, or developments in information technology the true (or joint) source of higher measured productivity in the financial sector. (Triplett and Bosworth, 2004, pp.29-31) Tracing such inter-sectoral connections, however, takes us away from the relative hand's-on simplicity of the sectoral approach and introduces the value-based complications of global measures.

But whatever the limitations of sectoral analysis, any location of a long term decline in the growth rate in productivity of the economy as a whole will be more convincingly found in the analysis of individual sectors than from aggregative statistics on trends in national productivity. And sectoral studies (e.g. Byrne et al., 2017), largely focusing on digital information and communications technologies (ICT), find declines in productivity growth even when correcting official figures for mismeasurement, including underestimates of price declines in high tech components. (Byrne, et al., 2016)[13] The problematic calculations of declining marginal productivity growth at the global (i.e. US national) level have thus been reinforced by comparable trends at the sectoral level in high tech industries, with a general consensus that a decline in productivity growth is indeed present. The question arises – is it appropriate to identify increases in productivity and, indeed, material standards of living, with 'innovations', identified in contemporary discussions with the activities of high tech industries?

Innovation and the trajectory of economic development

The dogma that 'innovation… is almost everything' in the search for productivity improvements, is so widespread that it becomes an almost inescapable truism: who can doubt that our present-day standard of living is the product of thunderbolts from the past - the steam engine, the electric motor, the semiconductor and so on? Without, at this point, questioning the proposition that the ultimate provenance of material improvement lies in these great innovations, let us consider whether, as an empirical proposition, innovations track straightforwardly with improvements in material prosperity in general, and specifically whether, in Schumpeterian fashion, these innovations have a provenance in capitalist, profit-making enterprises.

For the beginning of the twentieth century, a relatively straightforward version of a story affirming both of these propositions is easy to sustain – the US was the leader in rates of growth in GDP and GDP per capita, as well as being the home of the profit-making capitalist firms from which the flood of innovations came forth. An important contribution to these developments had been European achievements in engineering and science in the nineteenth and early twentieth centuries, but the harvesting of these achievements as full-fledged innovations took place predominantly through the aegis of large capitalist firms in the US, and secondarily in Imperial Germany. Contemporary economic observers largely overlooked the unprecedented developments that we now dub the Second Industrial Revolution: economic orthodoxy, as epitomised by Marshall (1922), continued to perceive the well-functioning capitalist economy through a nineteenth century focus on open markets and free trade, with firms acting as passive respondents to changes in demand and technology. It is not until very late in the day (see, for example, Romer, 1990) that a literature on the 'new economic growth' succeeded in integrating the notion of capitalist firms as focal points of innovation into mainstream economics.[14]

More troublesome is the post Second World War period for explaining the relationship between innovation and economic growth - the golden age of capitalism from the late 1940s to the early-mid 1970s. In fact, dramatic innovation played little role in the rapid growth across the capitalist world during the golden age. In the context of our present-day presumption that innovation is, uniquely, the fuel for economic growth and can be tautologically identified with technological change, (Byrne et al., 2016 and Bloom et al., 2017) note that the major venues for expansion during this rapid period of growth were technologies that were all up and running in the inter-war period such as consumer electronics (including television), chemical engineering (including chemical fertilizer), electrification and the associated electrical consumer goods, and the internal combustion engine, including devices used for agricultural expansion and development; antibiotics and jet aircraft were perhaps the two leading novel technologies. The exceptional economic growth that took place during the golden age was within the framework of established technologies, not only in recovering Europe, but in the US as well. It is thus highly questionable whether, in this period covering many decades, it is possible to assert that innovations track straightforwardly with improvements in material prosperity in a direct line of causation. On the contrary, the economic events in this period would appear to be more consistent with movement in the opposite, Keynesian or Verdoorn's law direction, by which a successfully functioning macroeconomic environment led to high rate of growth in productivity even in the absence of substantial innovation.

Furthermore, it can also be questioned whether, in the Schumpeterian manner, great innovations invariably have a provenance in capitalist, profit-making enterprises: the post Second World War period differs from that of the early twentieth century in the difficulty we find in linking many key innovations, in a straightforward way, to the activities of individual capitalist firms. The quintessence of modern innovation - the electronics revolution epitomised by the invention of the transistor (semiconductor) in 1947 - only began to have important economic repercussions in the US civilian economy in the period of relative stagnation beginning in the 1970s. And contrary to the notion of innovation having its provenance in capitalist animal spirits and the profit-seeking activities of firms (with the transistor emerging from the motivations of the near-monopoly phone company AT&T), the historical reality locates the earliest and perhaps crucial developments in semiconductors, and the electronics sector in general, to state, security-driven motivations from the US Department of Defense, and then a complex series of interactions between the state and profit making firms that led to the explosive development of the electronics industry. The important and continuing role for the state and other non-profit driven entities[15] in the electronics revolution and in other post war innovatory technologies, in contrast with the period at the beginning of the twentieth century, is not fortuitous – it has been driven by a form of market failure (i.e. the inability of the profit-driven free market to function appropriately) because of the growing role of 'science' (objective and reproducible ideas and protocols) in the invention and fabrication of new commodities and modes of work, as opposed to 'craft' (ideas and procedures embodied in individuals and specific institutions). Scientific developments are (practically by definition) more easily appropriated than craft skills by outsiders with sufficient intellectual preparation, a fact that can inhibit research linked to fundamental innovation by profit-making firms and has inserted the state and other non-profit driven entities into this role in the post Second World War environment in a wide variety of scientific and technological fields: it is progressively more unlikely that innovations of a fundamental kind will emerge from privately-owned, profit-making entities. The alienable nature of the (ever-growing) scientific component in technological development also helps to explain the growing centrality of disputes concerned with intellectual property rights and the desperate attempts on the part of firms and nations to protect 'their' technology.

The misleading formulations of Joseph Schumpeter have emerged as a kind of a placeholder for the process of innovation in mainstream economics, hoisting him to the status of the 'prophet of innovation', perhaps in embarrassment at the decades-long failure of the mainstream literature to concede that a Second Industrial Revolution had indeed taken place and to confront the consequences of this revolution for the process of innovation. This embracing of Schumpeter has involved an identification of innovation and technological improvement with discontinuous change. Schumpeter's approach to innovation is that 'it [is]… a "big" step and a "big" change'. (Schumpeter, 1939, p.101) The range of notions described as Schumpeterian are seemingly radical, but implicitly embody the orthodox neoclassical textbook presumption that all production takes place on the efficiency frontier,[16] with inputs being used optimally from the full range of available technological possibilities (a presupposition embodied in standard regression technique).[17] The statistical residual, this 'measure of our ignorance' which is often identified with Schumpeterian discontinuous innovation (see Bryne et al., 2016 and Bloom et al., 2017) swallows up a range of alternative sources of improvement. Given the fact that 'No engineer goes to the trouble and expense of developing techniques which he is certain will prove uneconomic', (Salter, 1969, p.14) much technological change does not take the form of a Schumpeterian thunderbolt – the setting up of a new production function - but is a mere substitution of one factor for another; (Rosenberg, 1976, pp.63-5) higher productivity may also emerge from Verdoorn's law considerations of economies of scale and learning by doing. Even more fundamentally, the presumption that an economy is operating on the frontier of its production function implicitly involves a denial of the possibility that sectors of an economy are using their existing resources and technology with less than optimal efficiency, a notion little in keeping with the economic history of industrial sectors and one that precludes the possibility that administrative and organisational reforms (the introduction of containerisation; the just-in time inventory system) might substantially enhance efficiency even in the absence of significant technological change.

The great majority of countries have been faced with the task of the assimilation and adaptation of new technologies, rather than their innovation: the US perspective of the necessity for innovation on the technological frontier acts perhaps as a distorting mirror in this regard. Wolf's use of statistics on trends in US productivity to serve as a surrogate for, presumably, world-wide developments in the limits of contemporary technology is likely to become increasingly deceptive with the emergence of important centres of such activity in other nations, as well as the difficulties of tracing, for instance, the national provenance of a technological innovation from a Swiss subsidiary of a US multinational such as IBM. But even in the case of indubitable cases of innovation, it is doubtful that the Schumpeterian image of a 'bombardment' from a large scale firm, (Schumpeter, 1943, pp.84-5) with its treacherous notion of creative destruction, is a useful one. One would think that the emergence of the semiconductor described above would be a quintessential example of a Schumpeterian innovation, but the substantive history deviates in crucial ways from the Schumpeterian archetype.[18] AT&T followed the Schumpeterian script by being an almost complete monopolist in the US phone business, but it was run, not by an entrepreneur, but by professional managers; the developmental phase of the semiconductor evidenced a further departure from strict Schumpeterian orthodoxy in the central role played by ferocious competition among firms and the substantial role played by state funding and direction.

Most significantly in the present context, the emergence of this general purpose technology (alongside the steam engine and electricity), far from being an explosive, discontinuous Schumpeterian event, had important elements of 'ordinary' economic activity involving the continuous diffusion of new techniques and learning by doing, with the new semiconductor sector building on the protocols, procedures, practical skills and intellectual capital of a range of existent industrial activities,[19] including an electronics industry built upon vacuum tubes (British: valves); the vacuum tube sector continued to exist alongside the newer one for several decades, suggesting that the change might be dubbed creative displacement rather than creative destruction.

Wolf and others are concerned with the relationship between the rate of change of productivity and the growth rate in GDP in time frames stretching over decades.[20] Once we depart from the Schumpeterian notion of discontinuous, Promethean innovation bequeathed to us by an entrepreneurial elite, we must give consideration to the infrastructural, institutional, intellectual and human contexts in which economic change takes place; such considerations may well play a decisive role in determining what kinds of public policy should be pursued, as we shall see below. Britain as the focal point of the First Industrial Revolution and the US of the Second shared certain characteristics in common in their respective periods (i.e. the late eighteenth and late nineteenth centuries): both were already high wage (and cheap energy) economies at the time of the initiation of their revolutions, suggesting the substitution of capital for high priced labour as a motivation for revolutions embodying labour-saving, high productivity forms of production; both were unified states with central governments possessing unquestioned sovereign power.(Allen, 2009) Certain differences emerge at the level of human capital development, with the mind-set, if not the intellectual attainments of entrepreneurial class in Britain reflecting, at least indirectly, the nation's central role in the scientific revolution of the seventeenth century, while the laggard position of the US in pure science through the early twentieth century meant that, in certain industries such as electrical machinery, foreign personnel inevitably played an important role. Educated elite groups may have played a disproportionate role in the adaptation of utterly new conceptions in the First industrial Revolution in Britain (Mokyr, 2011) and in the extraordinarily rapid adaptation of western science and technology in Japan after 1868. In the great majority of cases in the modern world, however, societies are charged with the adaptation and diffusion of techniques developed elsewhere, so that a focus on the development of a technological elite, as opposed to a broad-based human and institutional infrastructure, may be inappropriate.

Both Britain and the US inherited highly developed infrastructures of craftspeople and technicians from their pre-revolution periods, often from guild and guild-like institutions. (Epstein and Prak, 2008) A decisive departure from previous developments takes place in the Second Industrial Revolution, with the US (along with Imperial Germany) being at the forefront of mass, state-financed education, public policy initiatives that played a key role in the provisioning of personnel needed in the newly emergent forms of production but, perhaps even more significantly, for the staffing of bureaucracies in government and large firms, as well as in the burgeoning tertiary sector. In the post Second World War period, the unprecedented expansion in the US of higher education in all disciplines included a significant compensation for previous deficits in pure science and mathematics, one sufficient to make US universities and associated institutions the world centres of this range of disciplines.

Can we conclude that 'innovation… is almost everything' in the search for productivity improvements? Such a proposition can be asserted tautologically, but is a deceptive guide to the substantive history of economic development and may lead, as noted below, to an inordinate, and overly narrow fixation on productivity growth and the elixir of high technology. The historical record described above concerning the new general purpose technology based on the semiconductor emerged in the context of previous and concomitant broad-based commitments to high levels of institutional and human development in the US. This technology, based on the new physics of late nineteenth and early twentieth century Europe and the technological accomplishments of existing sectors in the US and elsewhere, was initially created to satisfy the practical needs of a great US monopoly, AT&T, for new switching devices for its telephone networks. We then observe the extraordinarily rapid overcoming of obstacles to the development and maturation of this technology by activities directed and financed by the US Department of Defense (DOD) for the purpose of creating weapons of mass destruction and little else: the transistor-based IBM mainframe computer emerged only in the 1960s, and the pioneering use of semiconductors in consumer electronics largely emanated from Japan. Having been invented and developed to serve the rather specific needs of AT&T and the DOD, it is only in the 1970s that the semiconductor-based electronics sector emerged as the source of a new general purpose technology, comparable to the steam engine and electricity, with applications in all aspects of the economy and society. This unexpected, even serendipitous set of developments has lent itself, as we shall see below, to the cultivation of a Teflon-moon shot myth, by which high tech developments have, invariably, salutary unintended consequences, promoting the notion that the magnitude of energy and effort devoted to high tech pursuits is of greater significance than whether the goals pursued are inherently socially desirable.

Is there 'no alternative'?

Let us recapitulate the mainstream consensus on the issues under consideration: *growth in productivity is 'everything'; the source of productivity growth is technological innovation (most likely emerging from profit-making enterprises), and the leading nations need to focus upon, and direct their efforts to, the development of high technology sectors.*

A response to this admirably succinct, coherent but utterly deceptive set of propositions will, of necessity, be a complex one. The notion that growth in productivity is 'everything' is, as we shall see below, an example of analysts being subject to capture by the very tools used to help focus their research efforts. The second proposition is that the source of productivity gains lay in discontinuous innovation (invariably identified in the contemporary literature with technological change), for which, it is suggested, there is little substitute: if we are on the frontier of the production function, there is no other ready source for improvement. In contrast to such a view, presented above is an indubitable case of innovation, the emergence of the post-war electronics industry in the US based on the semiconductor. This history has its list of elite heroes, but demonstrates, even in this paradigmatic case of innovation, the thin line between the process of innovation and that of diffusion. The latter aspect, especially, underlines the importance of broadly-based development of appropriate institutions, especially those related to human development (in the case of the US, its unparalleled university sector) and the presence of an appropriate infrastructure. Thus, the new semiconductor-based industry was built upon the human infrastructure and skills already in place in now obsolescent obsolete sectors such as vacuum tube manufacture. Rather than perceiving such sectors in the context of a hollowing out process of Schumpeterian creative destruction and bombardment, in which the labour embodied in such sectors is treated as a malleable commodity to be reallocated in this process of destruction, we can view this stock of labour, and the skills embodied in this labour, both individually and as a collectivity, as valued assets.

Drawing a line between the successful modification or adaptation of an older technology and the introduction of a new one is often difficult. The present-day enthusiasm for Schumpeter's seemingly radical focus on discontinuous technical change is one that preserves the standard dichotomy between an existent technology, for which a full set of blueprints is available, and an utterly new one. The awkward possibility of shades of grey – that economic outcomes are critically affected by the extent to which firms and societies successfully adapt to existent technologies – poses the possibility that the links between education and economic growth might not simply flow through the creation of new technologies (by, invariably, a small subset of the population), but are a function of the efficaciousness and creativity with which the society as a whole responds to these changes, or even to the more mundane challenges of maintaining and supervising of existing technologies, tasks which apparently consume the great majority of even academically trained engineers. (Edgerton, 2008, pp.100-102)

At a popular level, the innovative entrepreneur – James Dyson in the UK or Steve Jobs in the US – functions symbolically as the economy's saviour, returning the nation to its former unchallenged position. This cult of techno-nationalism 'assumes that the key unit of analysis for the study of technology is the nation: nations are the units that invent, have R&D budgets, cultures of innovation, that diffuse, that use technology. The success of nations, it is believed by techno-nationalists, is dependent on how well we do this'. (Edgerton, 2008, p.105) This is an odd fixation in the age of the multinational.[21] Simplistic notions of technical change as the source of material progress founder on the historical reality that, at both the national and individual level, the appropriation of these gains is a highly contingent matter. Thus, the post-World War II electronics revolution had its provenance in the US (and to a minor extent in Britain and the Soviet Union), but the successful adaptation of some aspects of these developments in Japan and then other nations in the Far East resulted in the virtual elimination of the production of mass consumer electronics in the US and the UK, with Asian nations cornering the bulk of world manufacture. This example reminds us that an over-much focus on gains from new technology may distract attention from other forms of national economic advantage gained from human intelligence, such as facility in design, or complementary forms of creativity, such as the managerial successes in quality control of Japanese manufacture. These manifestations of creative intelligence, unless associated with a specific patent or copyright, are likely to be precluded from consideration in, especially, statistical calculations, given the presumption of universal best practice in the use of existing technologies.

Returning to the primary proposition that growth in productivity is 'everything', note that it embodies the strong presumption that the source of this productivity growth will be (technological) innovation: if indeed we are functioning on the efficiency frontier, high tech is the only likely source of improvement. Thus, in the case of the US health care industry, with its grotesquely high costs and mediocre outcomes,(Commonwealth Fund, 2017) we are enticed with the benefits of enhanced productivity from a host of high tech innovations - large-scale data sharing, clinical decision support systems that use artificial intelligence and telemedicine, (Branstetter and Sichel, 2017) rather than the less exciting, and more contentious issues surrounding the high prices paid for pharmaceuticals, inflated administrative expenses and exceptional remuneration of doctors.

In a whole range of cases, we observe social decision-makers seeking a technological elixir to overcome social and economic difficulties.[22] In the Soviet Union of the 1980s, with its rusty buses and generally low standard of material life, the press was full of fantasies on the possible use of the latest technologies to leap over failures in the ordinary provision of goods and services, sometimes opining that the new computer technologies (which were emerging in capitalist countries) could at last make possible the production of a rationally calculated central plan: such a notion implicitly embodied a rather mechanical view of Marxian value theory, by which the costs for goods and services in the Soviet economy could be used, as in capitalist orthodoxy, as the basis for plan calculation. (see Auerbach and Sotiropoulos, 2014) Even without such an ideological underpinning, British Rail made a desperate attempt in the 1980s to introduce high speed trains in the context of a nineteenth century infrastructure and roadbed by using innovative solutions that enabled trains to tilt as they entered bends on the ancient track, (BBC News, 2015) a project that was ultimately unsuccessful. A last example involves the notion, currently fashionable, that developing countries in, for instance, Africa, can generalise their success in the adaptation of the mobile phone to harness contemporary technologies to 'leapfrog' over deficits in infrastructure. A recent report in the *Financial Times* is dubious: 'Some see in the power of technology an almost miraculous potential to solve problems that many governments, particularly in Africa, have failed properly to address; poor health, poor schools, lack of roads, lack of electricity and lack of jobs.' (Pilling, 2018)

What all of these examples have in common is the search for a technological elixir as an extrication from dysfunction and failure. And indeed, in the context of pressing world problems, it would be difficult to object to *ceteris paribus* alleviation in the form of technological manna dropped from heaven. Medical developments in the twentieth century are often upheld as primary instances of such 'magic bullets', with the story often retold that not even a Nathan Rothschild could be saved from dying of an infected abscess in 1836. This dramatic exemplification of the efficacy of modern medical science is somewhat neutralised by the historical reality that the great bulk of improvements in health and longevity since the time of Rothschild's death have been due to sanitation, nutrition and general aspects of economic development rather than high tech medical breakthroughs: infrastructural changes rather than magic bullets. (Fogel, 2004) In the context of the acute and urgent considerations surrounding climate change, it is impossible to avoid hoping that some technological breakthrough will solve or at least alleviate what appears to be an emergent catastrophe. (see, for instance Gabbatiss, 2018) But pursuing each of these possible paths to dealing with climate change until viability can be attained is costly. More importantly, a focus on technological breakthroughs as the sole path for dealing with climate change can offer the excuse, which many are eager to seize, that one can simply postpone dealing with the issue, since the implementation of strategies using existent technology are likely to be painful, involving various forms of consumption restriction.[23]

In our time, high technology functions as an elixir. In a popular literature emanating from the US and elsewhere, technology will solve social conundrums ranging from slow economic growth to obesity and climate change. The present-day rhetoric surrounding productivity growth is intimately linked to the mystique of the GPT: the electronics revolution had its origins in attempts to deal with concrete problems - the need for switching devices at AT&T and to facilitate the construction of weapons of mass destruction at the DOD. What emerged, however, was a general purpose technology which, like the steam engine and electricity, could engender productivity growth in all aspects of the economy.

With the emergence of this universal remedy,[24] we are only one step away from the Teflon-moon shot myth, (Emsley,1994) by which the pursuit of ambitious high tech projects (e.g. the 1969 moon landing) will have, invariably, favourable by-products (e.g. the myth that it led to the development of Teflon), promoting the notion that the magnitude of energy and effort devoted to high tech pursuits is of greater significance than whether the goals pursued are inherently socially desirable. In our post neoliberal age, such a stance can involve leaving the electronics industry to pursue market-based projects (as described above), even of a frivolous nature, with the hope (as I suspect Professor Goolsbee implicitly holds) that solutions to pressing issues such as climate change will emerge as a by-product. But since this new technology has emerged since the Second World War by way of public financing, should there not be a substantial element of public direction in the application of this technology (besides its use in the creation of weapons of mass destruction)? There is a tendency to treat new technology as a Promethean, uncontrollable force, one that is, at best, passively responsive to marketplace consumer demands, but not to public needs. Such notions do not correspond to the historical development of the electronics industry, which put in place, and successfully fulfilled, the concrete tasks before it (the development of switching devices; weapons), with by-products, only some of which were 'unintended consequences', emerging over decades. Why not channel the creative energies of this sector to socially desirable ends such as climate change alleviation and education, rather than treating any such developments as the fortunate, but accidental by-product of pursuits undertaken for other reasons?

Some final comments

Perhaps we need to reconsider why such a high priority is placed on productivity growth and hence innovation in the first place:

i. Slow productivity growth limits resources that will be available for low productivity sectors;
ii. Rises in GDP/per capita resulting from productivity growth are inherently beneficial from a welfare perspective;
iii. Aggregate demand considerations – slow productivity growth constrains the incentive for investment that leads to growth. In this case, the problem is not that a lack of productivity growth is due to insufficient investment, but the reverse: insufficient productivity growth is perceived as having a dampening effect on 'animal spirits' and therefore on investment and therefore aggregate demand.

In addition, however, I would add the following possibilities:

iv. A major reason (voiced *sotto voce*) for being concerned about a productivity slowdown is that we (i.e. the US, or the west) are in a race with 'them' (whoever they are): we have to keep up;
v. Are we simply mesmerised by our own measurements, which have taken on a life of their own?

An exclusive focus on productivity growth can lead to paralysis while awaiting technological manna from heaven, or focus energies in the direction of activities that register as 'productive' (i.e. will lead to growth in GDP per capita). The interaction of points iv and v above has registered in recent public policy discussions in the US, when opponents of environmental regulations, in the context of international competition, note the deleterious effects that these regulations might have on rates of growth in GDP per capita. An important contribution from the environmental literature, however, suggests that the latter notion may simply be based on a miscalculation of GDP as a measure of economic capacity. Any proper calculation of GDP and productivity must incorporate appropriate deductions for the degradation of the natural environment due to economic activity, just as firms must make an allowance for the depreciation of their capital in the calculation of their profits. (OECD,2014) And a range of enhancements to material life will not register productivity improvements at all.[25] In some cases, as suggested above, public action in increasingly unequal societies that is perceived to be purely 'distributional' (i.e. without effect upon GDP), such as improved housing facilities for households on lower incomes, may not only be intrinsically desirable but, in addition, have long term positive effects on the productive capacity of the households involved.

It would be a serious error, however, to find hidden sources of productivity growth in all forms of desirable social action such as increases in the quantity and quality of human resources devoted to care to the elderly, doctors' training in human interaction with patients and intensified tuition for students in social and political citizenship. The inordinate focus on the growth-innovation nexus ('Economic growth arises from people creating ideas [i.e. research]' Bloom et al., 2017) will direct effort and attention towards, for instance, of new technical devices for improving the delivery of recorded music to consumers, diverting resources from 'unproductive' expenditure on music tuition in schools to raise the quality of the music itself; longevity (a statistic not registering in GDP or productivity) might well be enhanced with greater efficacy through low tech social action to encourage better nutrition than high tech medical research.

Obviously, an over-riding of the declining effectiveness of Moore's law, or a technological fix to problems related to climate change would not be unwelcome. But rather than thinking about technological innovation as a magical elixir for solving problems (from weight loss to slowdown in GDP growth), perhaps we should think of it as part of the range of rational strategies that a society might use to cope with the problems confronting it. Thus, a reliance on technological change, as in point iii above, as a mechanism for stimulating animal spirits, may suggest that economists have no strategy for the maintenance of full employment except to await the next technological upsurge, a sad confession if true.[26] In broader terms, the panic over a productivity slowdown should be seen in the context of a need to reconceptualise the meaning of 'development', with rich countries re-examining - what should be our maximand? What is a 'good life', a 'good society'? These are not idle questions. There are particular dangers for poor countries whose strategy of development for the 21th century cannot merely retrace existing paths (largely concerned with industrialisation and the employment flowing from it) that may well not exist in the second half of the century. There is a need for a conceptualisation of development that involves something other than chasing productivity, one that embodies the human dimension as both a means and an end.

What then is the source of alarm surrounding a slowing down of the productivity growth rate? One seems to be an inordinate focus and hope for replication of developments in the

1990s in the US, where the coming on stream of a host of applications of the electronics revolution boosted growth to significantly higher levels than were evidenced before or after this period. In the context of a structure of income distribution so weighed against the great mass of potential consumers, is it (perhaps implicitly) postulated that a long term aggregate demand-based expansion is unlikely, and that only the descent of technological manna from heaven can sustain successful long term outcomes?

An additional element, however, is the spectre of productivity enhancement taking on a life of its own as a welfare criterion. In the wake of the financial crisis of 2008, *Schadenfreude* in the direction of those who, in 2004 (mentioned above) praised the productivity gains of the US financial sector come easily. But evaluation of gains in the retail sector, the largest single contributor to the resurgence of US productivity growth in the 1990s, (Triplett and Bosworth, 2004, p.233) raises more difficult questions. Thus, for Decker et al., (2014) the key question is whether the productivity enhancing change from the exit of low productivity 'Mom and Pop' stores and their replacement by higher productivity stores from large, national chains 'has been more in terms of subsistence or transformational entrepreneurs'. We see here an exclusive focus on productivity considerations, first upon the gains to consumers due to the enhanced productivity of the 'big box' retailers such as Walmart and then upon the effect of these changes on the composition of the entrepreneurial class. Gordon (2016, p.243), while noting that consumer gains may in fact be understated because of an 'outlet substitution bias' in the calculation of the consumer price index, permits a more negative interpretation to be placed on these developments that '[drive] local businesses into bankruptcy, [eliminate] jobs of people who might be forced to shift from the freedom of individual proprietorship to the minimum-wage non-union work environment of Walmart.' There are, furthermore, some passing hints (p.370) that these car-oriented developments have played a role in the wrecking of city and town centres. These objections, however, are too weak to challenge the centrality of productivity considerations, or to permit alternatives involving the planning of living space that might interfere with these 'natural' and 'inevitable' developments emanating from the Hayekian free market spontaneous order. We thus find that an international discourse centred round productivity, with origins largely in the US, yields 'objective' guidance on the rational organisation of land use and living space that just happens to conform with common practice in the US: there is no alternative.

With productivity enhancement taking on a life of its own as a welfare criterion, we find a central focus on the GPT of the age, the electronics sector, with the cargo cult-like hope that it can help us extricate ourselves from contemporary dilemmas. Such an approach evidences a lack of faith in social action. Substantial intervention from a GPT, is in Schumpeterian terms, a discontinuous, event, rather than part of the range of 'normal' improvements to material life (including 'normal' tech change) that a healthy society manifests in the context of solving the real problems before it. The chimera of a productivity slowdown is linked to a cry for help and exists alongside the seemingly contrary notion of an exhaustion of jobs due to AI. It is maintained not only at this emotional level, but is also buried in the cold, analytical structure of most economic analysis and research, which presumes that we are already functioning on the efficiency frontier of the economy, so that there is little else to do but await a technological elixir.

This assertion of inexorable laws in the economy has a parallel in macroeconomics. In 2007, the then former head of the Federal Reserve, Alan Greenspan, was asked for whom he was voting for president. He suggested that it didn't matter who was elected because, thanks to globalisation, policy decisions have been replaced by market forces. (Tooze, 2018, p.574) For Greenspan, the Ayn Rand free marketeer, this lack of freedom action was (as it is for all cult members) a desirable state. For the rest of us, the recognition that the assertion of ‘there is no alternative’ should be seen for what it is - a political stance - no matter how wrapped it is in scientific garb of a microeconomic or macroeconomic kind. There are indeed constraints on our actions, both individually and collectively, but the creation of false dilemmas and non-existent obstacles are a distraction from dealing with the problems before us.

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[1] An unavoidable complication to this simple concept is the fact that increases in output might take the form of the production of commodities with qualitative differences from existing ones, or of commodities not previously existing.

[2] There has also emerged a Great Divergence literature that examines why western Europe rather than in China (Pomeranz, 2001) or India (Yazdani, 2017) rose to economic predominance in the early modern period.

[3] Even here, issues can arise on the 'correct' prices to be attached to the machines. Wassily Leontief's famous input-output tables, the most prominent examples of attempts to represent an economy empirically in terms of its underlying productive relationships, rely on (market) price weights both within and between sectors for their construction.

[4] Labour inputs must be weighted for qualitative differences in skills, and typically, it is thought that wages should be expected 'to move closely with marginal products', (Bosler et al., 2016) a presumption partially supported in the literature, (Autor et al., 2008) but one lending itself to problems of endogeneity and circularity. (In the case of CEO-to-worker compensation, we have witnessed in the US a movement from 20 to 1 in 1965, 58 to 1 in 1989, 344 to 1 in 2000 to 312 to 1 in 2017 (Mishel and Schieder, 2018): such extraordinary stretching and gyration of relativities in remuneration gainsay the notion that these changes are anchored on anything as fundamental and stable as relative productivities.) An alternative approach to attaching weights to labour quality that avoids these problems includes an adjustment to the number of workers in the statistical analysis incorporating, among other variables, their years of schooling: (World Bank, 2000) such a procedure runs into the difficulty of how crudely the latter measure approximates improvements in academic achievement. (Hanushek and Woessmann, 2008)

[5] Perhaps even more contentious is the question of the measurement of capital, which has a long history and notorious list of problems, both theoretical and practical. Here I will mention only some of the latter issues. First, researchers in this area invariably have to rely on company statistics for the evaluation of tangible capital, which is traditionally calculated using historic cost valuations; complications emerge with the presence of capital of different technological vintages, as well as distortions in the measurement of historical trends with progressive modifications in recent decades of historic cost procedures to accommodate notions of replacement cost and net realisable value. The second, and perhaps the most pressing contemporary issue relates to intangible capital investment in areas such as healthcare, robotics and education, (Branstetter and Sichel, 2017) where evaluation of much of the new intangible capital such as AI, datasets, firm-specific human capital, and new business processes is difficult to quantify on the basis of traditional historic or replacement cost procedures: valuations will proceed on the basis of the stream of net revenues that this intangible investment is likely to yield, though such procedures will tend to capture returns that would otherwise lodge with residual TFP and therefore obviate the latter calculation. (Brynjolfsson et al., 2017) Most especially in a world of services, the creation of a work-force of 'productive', knowledgeable labour (e.g. nurses in an ageing population) is not merely complementary to working with technology, but is the essence of the job, in contexts in which gains in human welfare are often hard to quantify and may not register as increases in GDP.

[6] A general critique of this 'growth accounting' approach can be found in Auerbach (2016), Chapter 6.

[7] See Field (2011), Chapter 7 for historical movements in the US. Note that the levels of TPF growth in the 1930s (i.e. 1929 to 1941) were distinctively high in the recovery period 1934 to 1936 and during the war preparation-based recovery 1939 to 1941.

[8] The trend in the US towards a higher share of value added of national income in favour of capital as opposed to labour became a major issue of controversy when restated as a growing wage-productivity gap. (Michel, 2018) This is perhaps indicative of the pungency of the notion of productivity in public discourse.

[9] The problematic aspect of global productivity measures and their relationship to technological innovation may be illustrated by the fact that the US in the 1930s, 'the most technologically progressive decade of the century' (Field, 2003) in terms of inventions and patents granted, registered higher levels of TFP growth from 1929 to 1941 compared with 1948 to 1973 according to one measure, (Field, 2011, p.43) but substantially lower levels of increase in TFP compared with the later period when a correction is made for improvements in labour quality. (Bakker et al., 2016) The growth in the latter period, as noted below, was largely on the basis of developments, technological and otherwise, that were already up and running in the inter-war period or earlier.

[10] This distinction can be found in Byrne and Sichel (2017).

[11] Intersectoral movements do not appear in fact to be playing a decisive role in the present slowdown. (Byrne et al., 2016)

[12] Ironically, contrary to a present-day focus on productivity policy as a way of promoting macro success, it was justified in the UK in 1959 on the basis that macro success, i.e. full employment, had already been achieved. (Salter, 1969, p.1)

[13] Byrne et al. (2016) notes that 'biases in semiconductor prices… [have] a very small effect on GDP because faster true growth of real value added in semiconductors is offset by smaller true growth of real value added in products using the semiconductors. Semiconductor bias only matters for GDP because of exports and imports.' This observation underlines that while Wolf and others may use US productivity movements to trace world-wide trends, there are aspects of the measurements made (e.g. the levels of exports and imports) which are US specific, and may not be easy to generalise as indicative of a global trend.

[14] The Technocratic Planning Paradigm (TPP) of the early twentieth century (Auerbach, 2016, Chapter 3) imbibed far more of the spirit of the Second Industrial Revolution than did Marshallian orthodoxy, though it failed to give any special emphasis to the startling levels of innovation that were taking place. Only in a much later period do we see in Galbraith (1967) an attempt to integrate the TPP and notions from Schumpeter (to be discussed below) in a conception of planning and innovation as the central activities of the firm – a perspective that reached a sophisticated level of development in Nelson and Winter (1982); the classic historical exposition remains Chandler (1977).

[15] On the complex role of universities, science and economics, see Stephan (2012), especially Chapter 12.

[16] Note the contrast with Hayek (1949).

[17] Statistical tests have, in addition, a bias in favour of countable, clearly delineated measures of technological improvement (e.g. patents).

[18] The discussion here and below of the development of the semiconductor follows Auerbach (2016), Chapter 9.

[19] On the role of the culture of precision in the development of the electronics industry, see Winchester (2018), especially Chapter 9.

[20] TFP tends to move in tandem with economic activity because of labour hoarding by firms over the business cycle (Bhaumik, 2011) and, as suggested above, the tautological connection between measures of productivity and of economic activity. There is in fact a large 'real business cycle' literature that attempts to explain cyclical movements in terms of exogenous technological shocks (and therefore has links with Schumpeter, 1939) that will be put to one side here.

[21] In addition, locating 'country of origin' becomes increasingly difficult in the context of ubiquitous outsourcing by firms. (Smil, 2013, Chapter 1)

[22] Note the highly articulate critique in Sax (2018).

[23] See the review by Kolbert (2009) of climate change 'solutions' offered in Levitt and Dubner (2009).

[24] Whence the moronic expression from British journalism – 'chips with everything'.

[25] Gordon (2016) lists a host of inventions for the period 1870 to 1940 which increased the quality of life far more than their contribution to GDP (e.g. p.242 the introduction of cars meant health benefits from the elimination of horse manure on streets).

[26] Binswanger (2009) suggests the existence of a growth imperative in capitalist economies, with a zero growth economy not feasible in the long run.